A Quantitative Analysis of Extracranial-Intracranial Bypass Using Pedicled External Carotid Artery Donors

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Introduction

Cerebral revascularization techniques are essential components of cerebrovascular neurosurgery. External carotid artery (ECA) arterial pedicled donors are faster and safer than dual-anastomosis bypasses in patients with adequate flow. Several recent studies using intraoperative flow measurements have indicated that large diameter grafts are not always necessary to provide adequate flow to high-demand areas. The superficial temporal artery (STA), middle meningeal artery (MMA), and occipital artery (OA) are easily available ECA donors that can augment or replace flow to the anterior or posterior circulation.

Methods

The STA, MMA, and OA were dissected in 4 cadaveric specimens (8 sides). Frontotemporal, middle fossa, subtemporal, retrosigmoid, far-lateral, suboccipital, supracerebellar infratentorial, and occipital transtentorial approaches were performed on all sides. Depth of field, usable length, angle of exposure, diameter, proximal control, and maneuverability were quantified for all recipient vessels in each possible anastomotic configuration, as well as donor required length and diameter at the site of anastomosis.

Methods – Recipient Vessels and Approaches

Internal carotid artery (ICA)	Approach
Petrous (C2)	Middle fossa (MF)
Supraclinoid (C6-C7)	Frontotemporal (FT)

Middle cerebral artery (MCA)	Approach
Horizontal (M1)	Frontotemporal (FT)
Insular (M2)	Frontotemporal (FT)
Sylvian (M3)	Frontotemporal (FT)

Posterior cerebral artery (PCA)	Approach
Interpeduncular (P1)	Frontotemporal (FT)
Crural (P2A)	Frontotemporal (FT) Subtemporal (ST)
Ambient (P2P)	Subtemporal (ST)
Quadrigeminal (P3)	Surpacerebellar (SC)

Superior cerebral artery (SCA)	Approach
Anterior ponto-mesencephalic (APM)	Frontotemporal (FT) Subtemporal (ST)
Lateral ponto-mesencephalic (LPM)	Subtemporal (ST) Retrosigmoid (RS)
Cerebello-mesencephalic (CM)	Occipital-transtentorial (OT)

Posterior inferior cerebral artery (PICA)	Approach
Anterolateral medullary (ALM)	Retrosigmoid (RS) Far lateral (FL)
Tonsillomedullary (TM)	Far lateral (FL)
Telovelotonsillar (TV)	Suboccipital (SO)

Vertebral Artery (VA)	Approach
Extradural (V3)	Far lateral (FL)
Intradural (V4)	Far lateral (FL)

Methods – Donor and Recipient Measurements

Donor Variables	Description	Weight
Donor Length (L_D)	Minimum length of donor for tension-free anastomosis	1
Donor diameter (D_D)	Diameter of donor at L_D	1
Diameter mismatch (D_Δ)	$\lvert D_D - D_R \rvert$	3

Recipient Variables	Description	Weight
Depth of field (D_F)	Distance from center of craniotomy to anastomosis	1
Angle of exposure (A_E)	Degrees of circumferential exposure of recipient vessel	3
Proximal control (PC)	Score – ease of obtaining proximal control	2
Maneuverability (M)	Score – ease of maneuvering around anastomosis	2
Length of recipient (L_R)	Length of recipient vessel available for anastomosis	3
Diameter of recipient (D_D)	Diameter of recipient vessel at anastomotic site	0

Angle of exposure (A_E)		Proximal control (PC)		Maneuverability (M)	
0	<180°	0	Cervical ICA only	0	Impossible
1	180 - 270°	1	Control without clip	1	Difficult
2	270 - 360°	2	Clip control with significant dissection	2	Possible
3	360° + mobility	3	Clip control facilitated	3	Facilitated

Methods – Score Formulas

- 4 preserved cadaveric heads (8 sides) injected with blue/red latex
- Measurements taken for each combination of donor, recipient, and approach
- Measurements taken with caliper, except D_F (neuronavigation)
- For each recipient segment, average values are calculated
- Each average is scaled by dividing by maximum value in dataset
- For D_F, L_D, D_Δ, scaled values were inverted (higher values associated with increased anastomotic complexity)

$$D_{F(sc)} = 1 - \left(\frac{D_{F(avg)}}{D_{F(max)}}\right); \quad L_{D(sc)} = 1 - \left(\frac{L_{D(avg)}}{L_{D(max)}}\right); \quad D_{\Delta(sc)} = 1 - D_{\Delta(avg)}$$

- The remaining scaled values were calculated without inversion (higher values associated with decreased anastomotic complexity)

$$L_{R(sc)} = \frac{L_{R(avg)}}{L_{R(max)}}; \quad A_{R(sc)} = \frac{A_{R(avg)}}{A_{R(max)}}; \quad PC_{(sc)} = \frac{PC_{(avg)}}{PC_{(max)}}; \quad M_{(sc)} = \frac{M_{(avg)}}{M_{(max)}}; \quad D_{D(sc)} = \frac{D_{D(avg)}}{D_{D(max)}}$$

- $Score_R$ is calculated for each recipient segment using a weighted average:

$$\frac{(D_{F(sc)} * Wt(D_F)) + (L_{R(sc)} * Wt(L_R)) + (A_{R(sc)} * Wt(A_R)) + (PC_{(sc)} * Wt(PC)) + (M_{(sc)} * Wt(M))}{\sum_i Wt(i)}$$

- $Score_D$ is calculated for each donor vessel using a weighted average:

$$\frac{(L_{D(sc)} * Wt(L_D)) + (D_{D(sc)} * Wt(D_D)) + (D_{\Delta(sc)} * Wt(D_\Delta))}{\sum_i Wt(i)}$$

Results

The internal carotid artery was exposed at the petrous and supraclinoid segments and STA and MMA anastomoses were analyzed. The middle cerebral artery was exposed in the sylvian fissure and STA and MMA anastomoses were analyzed. All segments of the posterior cerebral artery were exposed using multiple approaches, and STA, MMA, and OA anastomoses were analyzed. The superior cerebellar artery was exposed by a combination of approaches and STA, MMA, and OA anastomoses were analyzed. The posterior inferior cerebellar artery was exposed using multiple approaches and OA anastomoses were analyzed. The vertebral artery was exposed with a far-lateral approach and OA anastomoses were analyzed.

The MCA (7.9), VA (7.6), and PICA (7.1) received the highest mean recipient scores. The PCA (4.4) and ICA (4.9) received the lowest mean recipient scores. The suboccipital (8.5) and far lateral (7.3) approaches received the highest mean recipient scores. The subtemporal (4.8) and middle fossa (5.3) approaches received the lowest mean recipient scores.

Results by Recipient

Recipient Score is calculated using D_F, A_E, PC, M, L_R, and D_R

Donor Score is calculated using L_D, D_D, and D_Δ

Higher scores indicate a more favorable anastomosis

	Recipient			Donor		
	Segment	Approach	Score	STA	MMA	OA
ICA	C2	MF	5.3	5.6	5.6	-
	C6-7	FT	4.6	5.2	3.2	-
MCA	M1	FT	6.5	5.8	4.0	-
	M2	FT	8.2	8.1	4.1	-
	M3	FT	9.0	6.9	4.9	-
PCA	P1	FT	4.7	6.0	5.2	-
	P2A	FT	3.8	6.2	4.8	-
		ST	4.3	7.1	4.9	-
	P2P	ST	3.4	7.4	5.0	-
	P3	SC	5.5	-	-	6.4
SCA	APM	FT	4.8	7.9	5.9	-
		ST	4.6	7.7	7.5	-
	LPM	ST	6.8	6.3	7.4	-
		RS	6.7	6.2	-	6.6
	CM	OT	6.0	-	-	5.8
PICA	ALM	RS	5.8	6.9	-	7.8
		FL	5.9	-	-	8.2
	TM	FL	8.2	-	-	6.7
	TV	SO	8.5	-	-	6.6
VA	V3	FL	9.8	-	-	7.3
	V4	FL	5.4	-	-	6.2

Results by Approach

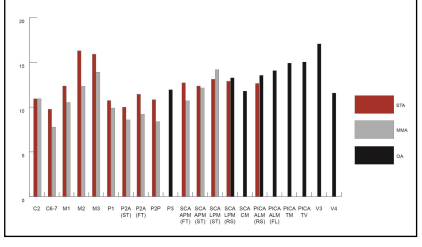
Recipient Score is calculated using D_F, A_E, PC, M, L_R, and D_R

Donor Score is calculated using L_D, D_D, and D_Δ

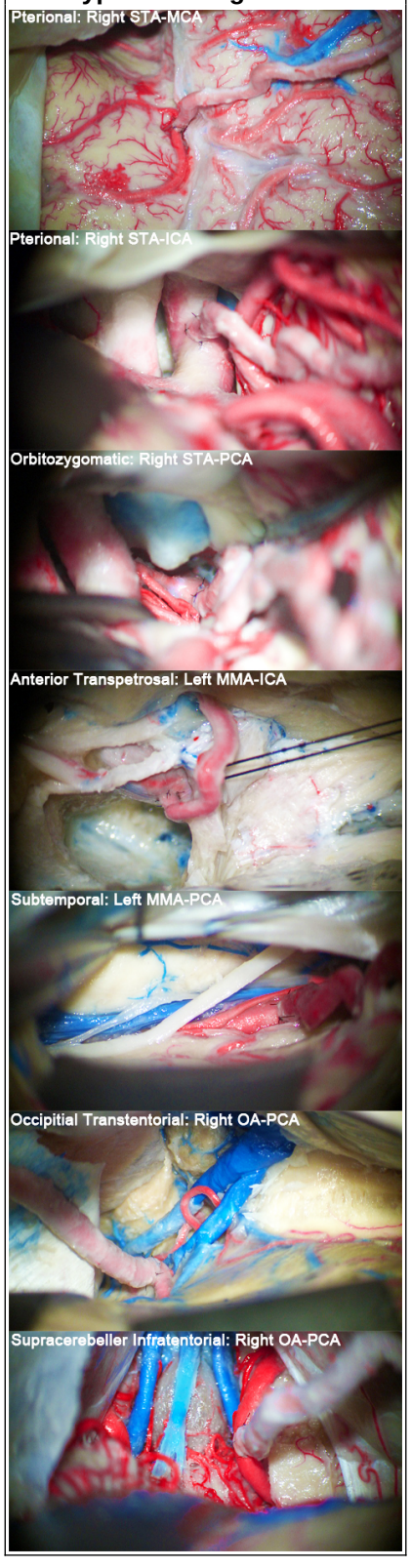
Higher scores indicate a more favorable anastomosis

Approach	Recipient		Donor		
	Segment	Score	STA	MMA	OA
Middle Fossa	C2	5.3	5.6	5.6	-
Frontotemporal	C6-7	4.6	5.2	3.2	-
	M1	6.5	5.8	4.0	-
	M2	8.2	8.1	4.1	-
	M3	9.0	6.9	4.9	-
	P1	4.7	6.0	5.2	-
	P2A	3.8	6.2	4.8	-
	APM (SCA)	4.8	7.9	5.9	-
Subtemporal	P2A	4.3	7.1	4.9	-
	P2P	3.4	7.4	5.0	-
	APM (SCA)	4.6	7.7	7.5	-
	LPM (SCA)	6.8	6.3	7.4	-
Supracerebellar	P3	5.5	-	-	6.4
Retrosigmoid	LPM (SCA)	6.7	6.2	-	6.6
	ALM (PICA)	5.8	6.9	-	7.8
Occipital transtentorial	CM (SCA)	6.0	-	-	5.8
Far Lateral	ALM (PICA)	5.9	-	-	8.2
	TM (PICA)	8.2	-	-	6.7
	V3	9.8	-	-	7.3
	V4	5.4	-	-	6.2
Suboccipital	TV (PICA)	8.5	-	-	6.6

Results – Composite Anastomotic Score



Extracranial-Intracranial Bypass Configurations



Conclusion

- Internal carotid artery: The MMA (5.6) scored equally to the STA (5.6) and should be considered for petrous ICA end-to-side anastomosis

- Middle cerebral artery: While surgical exposure of M3 (9.0) is facilitated, the M2 (8.2) is optimally matched by size with the STA (8.1 vs. 6.9 when paired with M3)

- Posterior cerebral artery: A sub-optimal recipient and should be avoided when possible, except P3 (5.5) to OA (6.4) using the supracerebellar-infratentorial approach
  Superior cerebellar artery:
  – For all possible posterior circulation bypasses using the subtemporal approach, the LPM (6.8) is the only favorable recipient
  – In the subtemporal approach the MMA (7.4) is the optimal donor and should be given strong consideration in addition to the STA (6.3)

- Posterior inferior cerebellar artery: Anastomoses using the distal TM (8.2) and TV (8.5) segments to the OA (6.7 and 6.6) are optimal using a far lateral and suboccipital approach, respectively

- Vertebral artery:
  – The V3 (9.8) segment received the highest overall recipient score due to its superficial and extracranial location
  – V3 to OA bypass received the highest combined score and likely represents the easiest overall anastomosis